N88-23253

MODAL FORCED RESPONSE OF PROPFANS IN YAWED FLOW*

G.V. Narayanan
Sverdrup Technology, Inc.
(Lewis Research Center Group)
NASA Lewis Research Center

ABSTRACT

This research is part of the ongoing NASA Lewis aeroelastic research program on propfans. A modal forced response method for propfans in yawed flow is presented here. This capability now exists in the Aeroelastic Stability and Response of Propfan (ASTROP3) code that has been developed at NASA Lewis.

The ASTROP3 code by Kaza et al. (1987) uses three-dimensional steady and unsteady cascade aerodynamics by Williams and Hwang (1986) and a NASTRAN finite element model to represent the blade structure. In addition, many utility programs exist in ASTROP3 that help in both the preprocessing of the NASTRAN model and the postprocessing of modal response results. This presentation will highlight the postprocessing work that computes the blade vibratory displacements and stresses in yawed flow.

Code validation for obtaining the blade vibratory displacements and stresses using this method was done successfully by comparing one-per-rev measured blade vibratory stresses and calculated values for two single-rotation propfan models. Data from the SR5 model with 10 blades and SR3 model with 8 blades are used for the code validation. The correlation between theory and experiment is good.

*Work performed on-site at the Lewis Research Center for the Structural Dynamics Branch.

C-5

INTRODUCTION

The presentation will give a description of the propfan models and outline a method of calculating modal forced response of propfans in yawed flow. In particular, the discussion will be on the postprocessing routines developed and implemented for computing vibratory displacements and stresses in ASTROP3. In addition, the comparison of measured and calculated stresses for the SR5 and SR3 propfan models will be presented for selected cases.

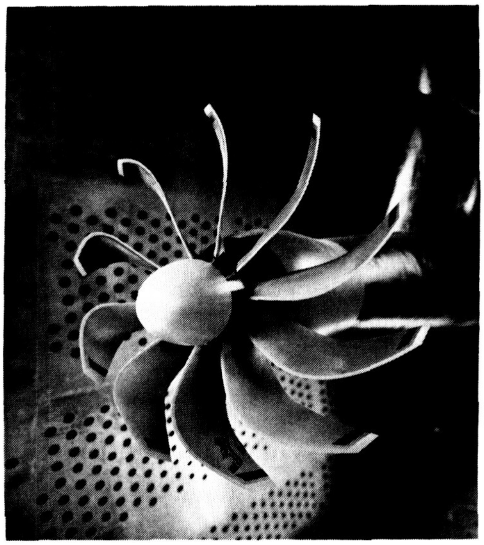
- PROPFAN MODEL DESCRIPTION
- MODAL FORCED RESPONSE METHOD IN ASTROP3
- POSTPROCESSING ROUTINES
- COMPARISON OF MEASURED AND CALCULATED RESULTS

CD-88-32829

PROBLEM DEFINITION

The models considered for analyses are the SR5 propfan with 10 blades and the SR3 propfan with 8 blades. In both these propfans, the blades are made of titanium. The SR5 propfan installation in the Lewis 8- by 6-foot wind tunnel is shown below at the left. For these propfans, the given parameters in the analysis are the inflow angle, the rotor speed, the wind tunnel velocity of air, and the blade pitch setting angle. The blade vibratory displacements and stresses are solved for in the analysis.

SR5 PROPFAN



CD-88-32830

PROBLEM DEFINITION
MODELS

MODELS
- SR5 (10 BLADES)
- SR3 (8 BLADES)
- TITANIUM

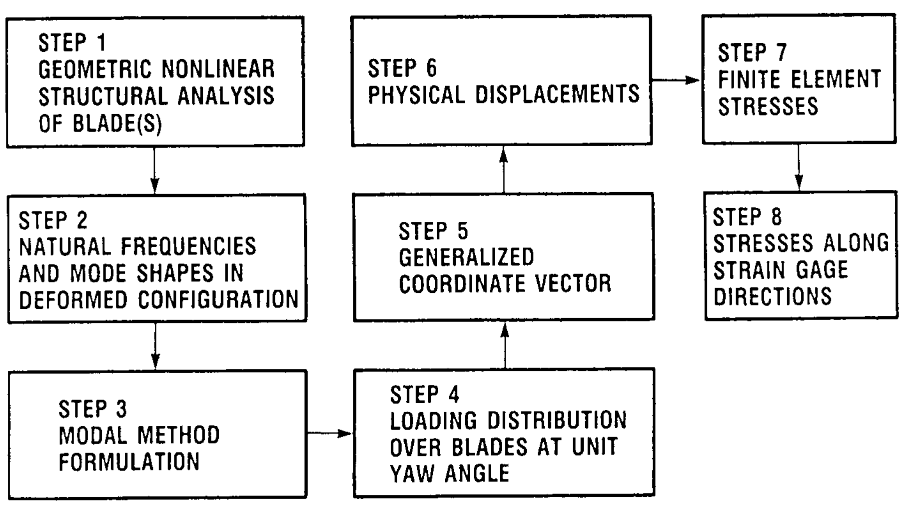
GIVEN PARAMETERS
- INFLOW ANGLE
- ROTOR SPEED
- TUNNEL VELOCITY
- BLADE PITCH SETTING ANGLE

CALCULATED PARAMETERS
- BLADE VIBRATORY DISPLACEMENTS AND STRESSES

CD-88-32831

FLOWCHART OF MODAL FORCED RESPONSE ANALYSIS

The modal forced response analysis consists of eight steps, as shown in the blocks below. In step 1, finite element analysis is used to obtain steady-state deflections and the differential stiffness matrix (Lawrence and Kielb, 1984). In step 2, the differential stiffness matrix generated in step 1 is used to determine the blade natural frequencies and mode shapes in the deformed state. In step 3, the generalized equations of motion are formulated for the system. In step 4, the calculation of the airloads distribution over the rotating blades inclined at a unit yaw angle is done (Williams and Hwang, 1986). In step 5, the solution of the generalized coordinate values for the given operating conditions is obtained. These values are referred to as modal participation factors. In steps 6 and 7, the physical displacements and finite element stresses are retrieved by appropriate modal summation using modal participation factors. Lastly, in step 8, the finite element stresses are transformed into normal and shear stresses along the measured blade strain gage directions. Steps 1 through 5 have been discussed by Kaza et al. (1988). Steps 6 through 8 will be discussed in detail in this presentation.

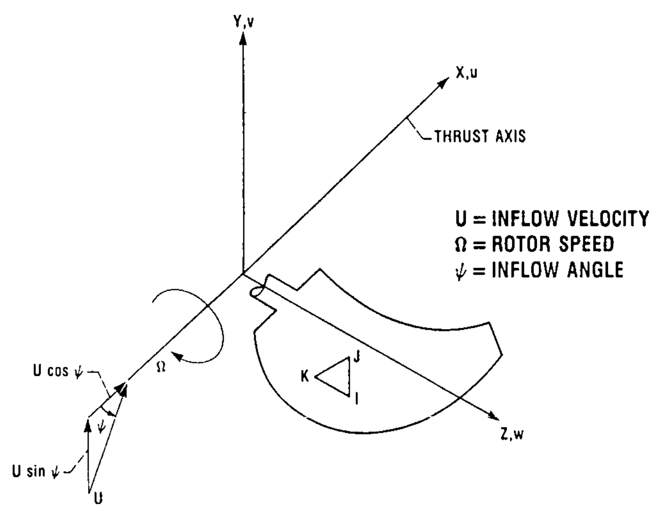


CD-88-32832

COORDINATE SYSTEMS

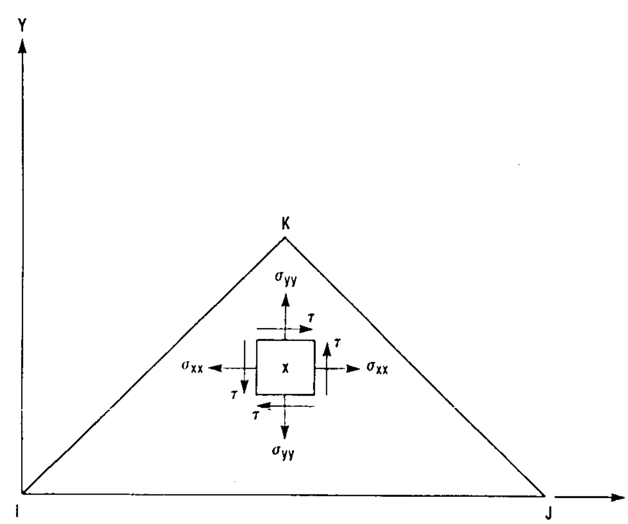
The global coordinate system used in ASTROP3 is shown at the left. The global X-axis is along the propeller thrust axis. The blade plane of rotation is the Y-Z plane. The physical displacements along X-, Y-, and Z-axes are represented by u, v, and w, respectively. A typical triangular finite element is shown on the blade at the left. The stresses on the finite element are in the local element coordinate system. This is shown in the figure on the right. Normal and shear element stresses in the local x- and y-axes directions are represented by σ_{xx}, σ_{yy}, and τ, respectively.

GLOBAL COORDINATE SYSTEM



CD-88-32833

LOCAL ELEMENT COORDINATE SYSTEM



CD-88-32834

PHYSICAL DISPLACEMENT

The physical displacements on the blade can be obtained by appropriate summation of the modal displacements using participation factors $\{(q_j), j=1,NM\}$ as modal weights. The summations of the modal displacements are written in mathematical form below. A routine called TOTAD exists in ASTROP3 that performs this set of calculations. Depending on the need, one can obtain either amplitude or phase of physical displacement at a grid, or both of these values.

PHYSICAL DISPLACEMENTS ON BLADE

$$u_i = \sum_{j=1}^{NM} q_j \, u_{ij}$$

$$v_i = \sum_{j=1}^{NM} q_j \, v_{ij}$$

$$w_i = \sum_{j=1}^{NM} q_j \, w_{ij}$$

WHERE i = GRID NUMBER AND j = MODE NUMBER

CD-88-32835

PARAMETERS

NM	NUMBER OF MODES
q_j	GENERALIZED COORDINATE VALUES FOR MODE j
(u_{ij}, v_{ij}, w_{ij})	MODAL DISPLACEMENT VECTOR AT GRID i FOR MODE j

CD-88-32836

ELEMENT STRESS

Similar to physical displacements, the element stresses on the blade can be obtained by appropriate summation of the modal stresses using participation factors {(q_j),j=1,NM} as modal weights. The summations of the modal stresses are written in mathematical form below. A routine called CESTRS exists in ASTROP3 that performs this set of calculations. An associated routine, called RDSTRS, has been developed to read the modal stresses on the blade for all modes.

ELEMENT STRESSES ON BLADE

$$(\sigma_{xx})^E = \sum_{j=1}^{NM} q_j \, (\sigma_{xx})_j^E$$

$$(\sigma_{yy})^E = \sum_{j=1}^{NM} q_j \, (\sigma_{yy})_j^E$$

$$(\tau)^E = \sum_{j=1}^{NM} q_j \, (\tau)_j^E$$

WHERE j = MODE NUMBER AND E = ELEMENT NUMBER

CD-88-32837

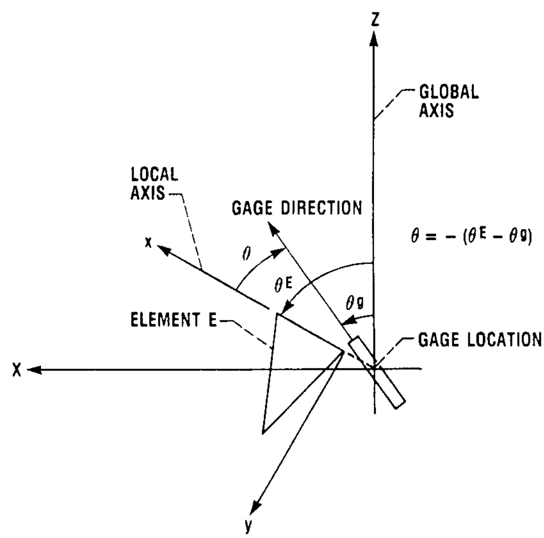
PARAMETERS

NM	NUMBER OF MODES
q_j	GENERALIZED COORDINATE VALUES FOR MODE j
$(\sigma_{xx})_j^E$, $(\sigma_{yy})_j^E$, $(\tau)_j^E$	MODAL STRESSES ON FINITE ELEMENT E FOR MODE j

CD-88-32838

CALCULATED ELEMENT AVERAGE STRESS IN GAGE DIRECTION

Let g represent a uniaxial strain gage located on the blade in a direction that makes angle θ^g with the global Y-axis. The figures below show the element stress and gage directions. It can be noted that the gage location may not coincide with the centroid of any of the finite elements of the blade. In such a case, the finite elements surrounding gage g are identified from the geometry of the blade. For the element surrounding gage g, element stresses are transformed to be in the gage direction. The stress transformation relations are also given below. These transformed stresses are used to compute an element average stress in the gage direction. A routine called GAGEST exists in ASTROP3 that performs the computation of normal and shear stresses in strain gage directions. The stress averaging of the calculated element stresses in the strain gage direction is done in ASTROP3 by CESTRS routine.



WHERE θ = ANGLE BETWEEN ELEMENT x-AXIS AND GAGE DIRECTION

CD-88-32839

ELEMENT STRESS IN STRAIN GAGE DIRECTIONS

$$(\sigma_n)_T^E = \frac{(\sigma_{xx})^E + (\sigma_{yy})^E}{2} + \frac{(\sigma_{xx})^E - (\sigma_{yy})^E}{2} \cos(2\theta) + (\tau)^E \sin(2\theta)$$

$$(\tau)_T^E = \frac{(\sigma_{xx})^E - (\sigma_{yy})^E}{2} \sin(2\theta) - (\tau)^E \cos(2\theta)$$

CD-88-32840

AVERAGE ELEMENT STRESS IN GAGE DIRECTION

$$(\sigma_n)^g = \frac{1}{(NE)} \sum_{E=1}^{NE} (\sigma_n)_T^E$$

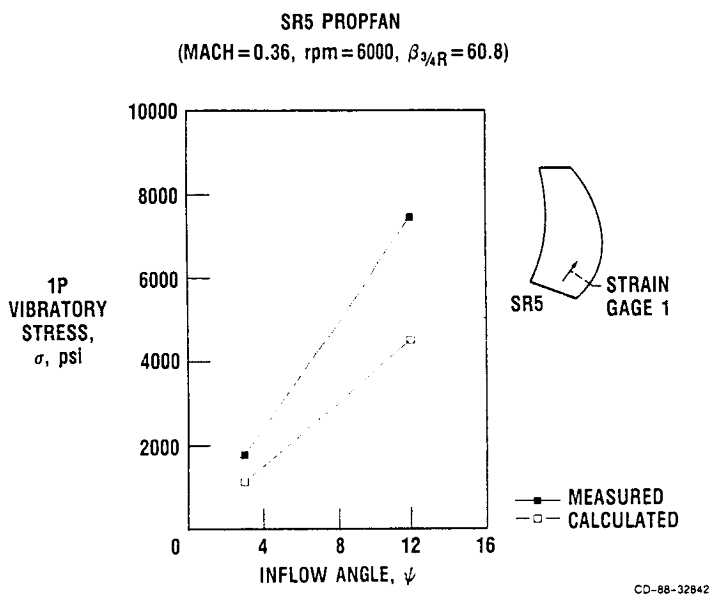
$$(\tau)^g = \frac{1}{(NE)} \sum_{E=1}^{NE} (\tau)_T^E$$

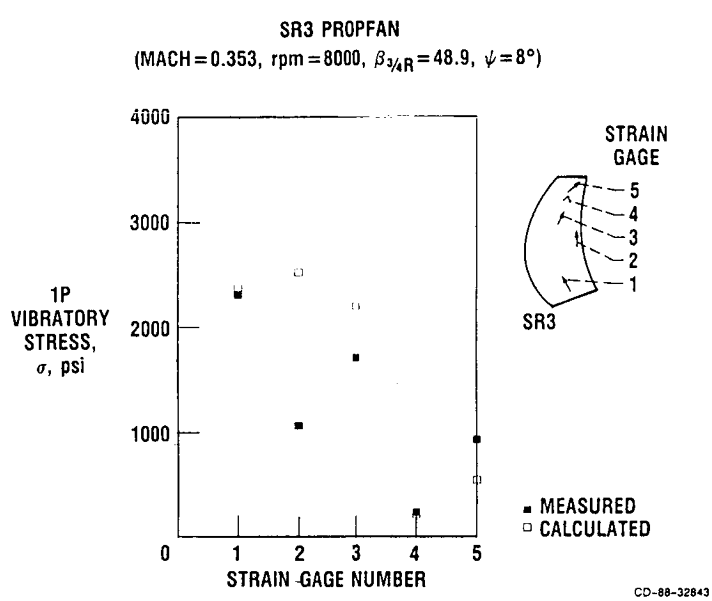
WHERE NE = NUMBER OF ELEMENTS SURROUNDING GAGE g

CD-88-32841

COMPARISON OF MEASURED AND CALCULATED STRESSES

For the SR5 propfan model, the normal stresses on an inboard strain gage for two inflow angles are used for comparison of measured and calculated stresses. Also, the calculated stresses for four strain gages are compared with experimental values for the SR3 propfan model. The calculated values for SR5 are lower than the experimental values by 20 to 50 percent, whereas the calculated values for SR3 are higher than the experimental values by 10 to 50 percent except for strain gage 2.





SUMMARY

A method for the computation of vibratory displacements and stresses for propfans in yawed flow is presented. This capability now exists in ASTROP3.

- MODAL FORCED RESPONSE ANALYSIS FOR PROPFANS IN YAWED FLOW DEVELOPED
- USES 3-D STEADY AND UNSTEADY CASCADE AERODYNAMICS
- CALCULATES BLADE VIBRATORY DISPLACEMENTS AND STRESSES
- PART OF ASTROP3 CODE

CD-88-32844

REFERENCES

Kaza, K.R.V. et al., 1987, "Analytical Flutter Investigation of a Composite Propfan Model," AIAA Paper No. 87-0738, NASA TM-88944.

Kaza, K.R.V. et al., 1988, "Forced Response of Metallic and Composite Propfan Models in Yawed-Flow," AIAA/ASME/ASEE/SAE 24th Joint Propulsion Conference and Exhibit, Boston, Massachusetts, July 11-14, 1988.

Lawrence, C., and Kielb, R.E., 1984, "Nonlinear Displacement Analysis of Advanced Propeller Structures using NASTRAN," NASA TM-83737.

Williams, M.H., and Hwang, C., 1986, "Three-dimensional Unsteady Aerodynamics and Aeroelastic Response of Advanced Turboprops," AIAA 27th Structures, Structural Dynamics and Materials Conference, Part 2, New York, pp. 116-124.